

The Effect of Bioactive Glasses in Air Abrasion Procedures

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Citation: Masood H, Gillam D, Hill RG. (2020) The Effect of Bioactive Glasses in Air Abrasion Procedures. J Orthod Craniofac Res 2: 109. DOI: 10.29011/JOCR-109.100109

Received Date: 14 July 2020; **Accepted Date:** 24 July 2020; **Published Date:** 31 July 2020

Abstract

Objective: To analyse the effect of particle size and shape of a new bioactive glass BioMinF® on air abrasion compared to an air polishing powder (Sylc®) using an enamel substitute material (Macor®).

Method: The materials used in the study were: 1) Macor®, (Precision Ceramics UK) 2) BioMinF®: 500gm of glass frit (Cera Dynamics Ltd, UK) and 3) Sylc®: Sylc 45S5 glass (Velopex International, UK). An AquaCare Air Abrasion & Polishing System (Velopex) with a hand piece with a 0.8 mm diameter tip was used with a 2mm thick Macor® sheet with a feed rate of 1 and an air pressure of 2 bar. The BioMinF glass was milled for 45 seconds in five batches each containing 100 gm of BioMinF® frit using a milling machine (Gy-Ro Mill, Glen Creston, and London). The angular particles produced were separated using different sieves to produce <38 micron, 38-63 microns, 63-80 microns, 80-125 microns and 125-250 microns particle size(s) respectively. To obtain the rounded particles, samples of 38-63, 63-80 and 80-125 micron powders were ball milled for 20 minutes. Evaluation of the samples was undertaken using Particle size Analysis, SEM and White Light Profilometry techniques.

Results: Particle size, has a direct effect on air abrasion with abrasivity correlating with the D90 particle size. Sylc® was demonstrated to be more abrasive than BioMinF®.

Conclusion: The results from the present study would suggest that air polishing with BioMinF® would be a better choice for polishing enamel with the advantage of localized fluoride release. However further studies are required using different substrates that more closely mimic human enamel.

Keywords: Air abrasion; Bioactive glasses; Macor® Enamel substitute material; Particle size analysis; Sem; White light profilometry

Introduction

Air abrasion procedures are a more conservative, less traumatic alternative to the high-speed air turbine hand pieces when used to remove tooth structure as well as polishing the tooth surface to remove stain. There are numerous powders used in air abrasion procedures such as sodium bicarbonate, glycine, erythritol and bioactive glasses with varying degrees of abrasivity to the tooth surface [1]. One of the problems with these powders was that the finer particles had a tendency to aggregate forming larger particles which would impact on the flow rate through the air abrasion dental hand piece and to negate this effect so-called anti-clumping agents such as fumed silica or solid glass beads are often added to facilitate the flow of the powder during the dental

procedure [2].

A 45S5 (Sylc®) calcium sodium phospho-silicate glass and alumina material has been previously used in air abrasion procedures [3-5]. The 45S5 glass is harder than tooth enamel and can be used to cut tooth cavities whilst minimising patient discomfort. However the glass is not hard enough to cut efficiently. For polishing or cleaning teeth this glass is too hard and abrades the tooth surface. According to Skallefold et al. [6] one of the distinct characteristic features of bioactive materials was the ability to interact with the biological environment such as in bone and teeth to elicit a biological response forming hydroxyapatite. A new less abrasive Bioactive fluoride (BioMinF®), containing glass with a lower Hardness (4.4GPa vs. 4.68GPa [Sylc®]) was developed for air abrasion/polishing procedures with the additional benefit that the release of fluoride from this glass over a longer period of time (slow release) and forming a more acid resistant fluorapatite. Currently there are limited data on the effect of particle shape and

size of these bioactive glasses on air abrasion.

Objective

The objective of the present pilot study was to analyse the effect of both particle size and shape of a new bioactive glass BioMinF® on air abrasion and compare it to Sylc® using an enamel substitute material (Macor®).

Materials and Methods

The materials used in the study were as follows: 1) Macor®, (Precision Ceramics (UK)) used as an enamel substitute analog (4 sheets: 2 mm thickness/50 mm square), 2) BioMinF®: 500gm of glass frit (Cera Dynamics Ltd, UK) and 3) Sylc®: Sylc 45S5 glass (Velopex International, UK). The dried glass was milled for 45 seconds in five batches each containing 100 gm of BioMinF® frit using a milling machine (Gy-Ro Mill, Glen Creston, London). To separate the different angular particle sizes, different sieves of size 38,63,80,125 and 250 µm were used. Particles were separated in different sizes of <38 µm, 38-63 µm, 63-80 µm, 80-125 µm and 125-250 µm. To obtain the rounded particles, samples of 38-63, 63-80 and 80-125 µm were ball milled for 20 minutes. Evaluation of the samples was undertaken using Particle size Analysis, Scanning Electron Microscopy (SEM) and White Light Profilometry techniques as follows:

a) Particle Size Analysis

A Mastersizer 3000 laser diffraction analyser with an Aero Dry Powder Disperser (Malvern Panalytical Ltd, Malvern UK) was used to measure particle size distribution from 10nm up to 3.5mm.. A small quantity of each sample was required for the analysis which produced D10, D50 and D90 of glass samples.

b) Scanning Electron Microscopy (SEM)

SEM images were taken of the glass samples.

c) White Light Profilometry

Each Macor® sheet was sectioned into multiple compartments by the permanent marker, followed by labelling on x and y-axis of the sheet prior to the analysis. The cut depth of the Macor® sheet was undertaken using White Light profilometry (Proscan 2000 Scantron Industrial Products Ltd, Taunton UK) with each compartment of the Macor® sheet scanned individually at the commencement of the scan, followed by a complete scan of the sheet for each of the glass powders used in the air polishing procedure at the end of each scanning session. An Aqua Care Air Abrasion & Polishing System (Velopex International, Medivance Instruments, Ltd UK) with a hand piece with a 0.8 mm diameter tip together with a disposable plastic tip was used 4mm from the Macor® sheet with a feed rate of 1 and an air pressure of 80 psi (551.5 kPa to evaluate the glass powders on the Macor® sheet. The plastic tips were changed following each application to standardize the experiment. Each sample was air polished at a 90° angle to the Ma-

cor® sheet for 5 and 10 seconds with each of the glass powders. The amount of powder present in the chamber was checked and always filled to the same level prior to each application to ensure reproducible and standardized conditions. The procedures for the main study are described in the Table 1.

Task	
1	BioMinF® was obtained in the form of frit, which was Gy-ro milled.
2	After Gy-ro milling, the glass was sieved and divided into different particle sizes.
3	A section of angular particles was ball milled.
4	Particle size analysis was undertaken on all the samples.
5	SEM images were taken to confirm the particle shapes
6	Air Abrasion was performed on the Macor® sheet with different glass powders under constant conditions.
7	The Macor® sheet was observed under White light Profilometry to determine any surface depth and volume changes.

Table 1: Outline of the procedures in the main study.

Results

Prior to the main study a pilot study was performed on a Macor® sheet was suitable for determine whether the material would be robust when using air abrasion. Following a successful evaluation of the material, the results of the particle size analysis obtained for glass powders are shown in Table 2.

a) Particle Size Analysis

	Particle size (µm)		
	D10	D50	D90
Batch	20.5	52.5	88.4
	11.5	66	88.4
	10.4	84	158
	127	192	282
	10.5	50.3	87.9
	14.7	75.4	126
	84.2	123	179
Sylc®	45	71	108

Table 2: Particle size analysis of the samples.

Key: D 90 gives the value in µm for which 90% of the glass particles are smaller and 10% are bigger D 50 gives the value where 50 % of the glass particles are bigger and 50% are smaller and D10 gives the value for which 10% are smaller and 90% bigger.

b) Scanning Electron Microscopy (SEM)

SEM was used to check the morphology of glass particles. These SEM images were taken with a magnification of 500x. Particle size differences were evident in the SEM images in Figures 1 and 2. Fine particles were observed more in the smaller particle size fractions than in the larger particle size fractions, which may be a result of the aggregation of the glass particles in the sieving process, which makes it difficult to separate them cleanly. There is evidence of their presence as seen in Figures 1 and 2. The ball milled particles were not completely round but had fewer sharp edges than the Gy-Ro milled particles (Figure 2). Sylec® particles were more uniform in size and shape as compared to the BioMinF samples with fewer fine particles (Figures 2) attaching to their surface. A limited number of fine particles were also observed in Sylec® glass powder, which resulted in a sharper less polydisperse particle size distribution that probably contributes to good particle flow during the air abrasion procedure.

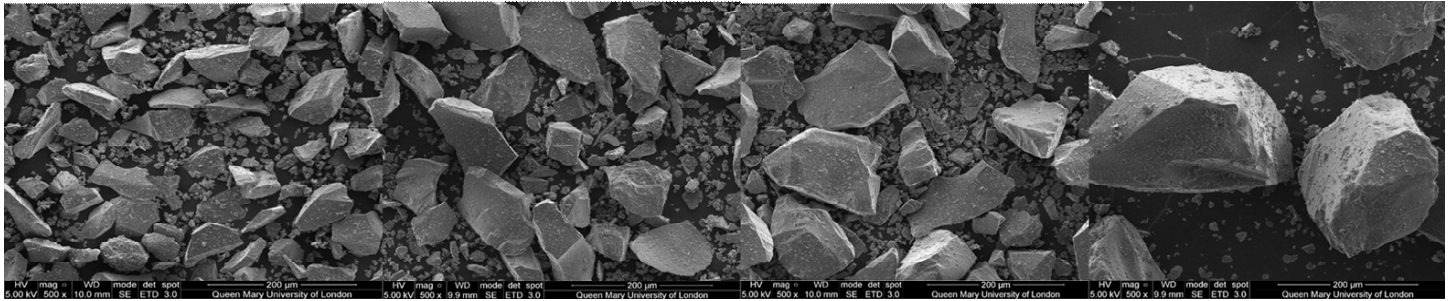


Figure 1: a-d Angular particles of BioMinF®.

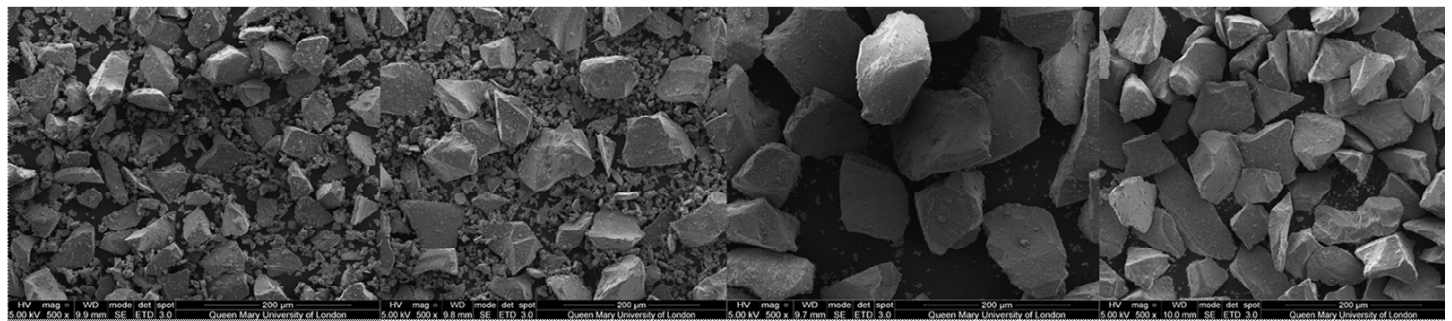


Figure 2: a-d Comparison of Ball milled particles of BioMinF® and Sylec®.

c) Air abrasion on a Macor® sheet

Air Abrasion was undertaken for 5 and 10 seconds with a feed rate 1, pressure 2 bar and distance of 4mm. The following results were obtained (Table 3).

Glass	Cavity Depth (microns)	
	5 second	10 seconds
38-63 angular	267	419
63-80 angular	296	512
80-125 angular	376	625
38-63 ball milled	252	390
63-80 ball milled	297	508
80-125 ball milled	425	659
Sylec®	368	715

Table 3: Comparison of the cavity depths obtained by different samples of BioMinF® and Sylec®.

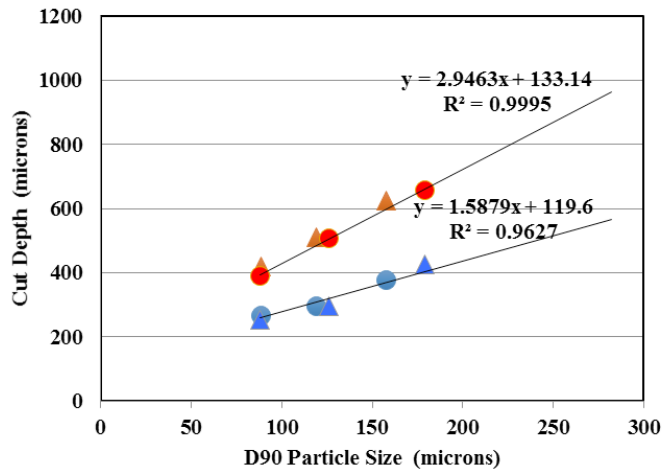


Figure 3: Cut Depth plotted against D90 Particle size. Triangles = Angular Particles Circles =Ball Milled (Rounder Particles). Red points=10s Blue=5s air abrasion.

For the D90 glass powders there was a good linear correlation observed between the D90 particle size and cut depth for both the angular and ball milled particles with all R^2 values >0.95 . There was no correlation with the D10 values and a poorer correlation with cut depth for the D50 particle size. The fact that the D90 particle size correlates with the cut depth indicates that the larger particles in the distribution dominate the material removal process. (Figure 3) shows the plot of cut depth against D90 particle size. At 10 seconds both angular and ball milled particle shapes demonstrated a similar cutting action in all the size ranges and the data for angular and ball milled overlaps. The same occurs for the samples abraded for 5s. However the slope of the linear regression line is approximately halve that for the samples abraded for 10s (1.5879 cf 2.9463) Overall, the effect of a 10-second challenge was similar in effect to the 5 second challenge in terms of the response in cutting depth with no real differences observed between the particle shape, but both particle size and time of abrasion had a clear effect.

There was a relatively good correlation observed between D50 particle size and cut depth. In all cases, the cutting depth increases with an increase in particle size for the ball milled and angular particles. A small difference was observed at the higher particle size where the angular particles were more abrasive than the ball milled particles. The linear correlation for both the angular and ball milled particles ($R^2 = 0.9674$ and 0.9913) respectively with no real differences observed between the different particle shapes. No real differences were observed after 10 seconds of air abrasion between the angular and ball milled particles both particles increased the cutting depth although a greater particle depth was observed with the higher particle sizes. The linear correlation for both the angular and ball milled particles ($R^2 = 0.9993$ and 0.9888) respectively with no real differences observed between the

different particle shapes differences between particle size(s) were quite evident. The D10 particle size has a poor correlation with the cavity depth following a five and ten second air abrasion which may have been due to the larger particle sizes having a more dominant effect on the abrasivity of the glass than the smaller particle.

Discussion

Bioglass material in the form of a 45S5 glass has been used in both medical and dental applications such as bone grafts, hard tissue repair, cutting dental cavities, toothpastes (with/without Fluoride) and more recently air abrasion/polishing procedures [3,4,7-14]. According to Banerjee et al. [4], bioactive glasses compared favourably to using sodium bicarbonate powder in removing stain and in terms of patient comfort during the procedure. Previous studies evaluating air abrasion using bioactive glasses have utilised the human tooth model (enamel) to determine the effect of these powders on the tooth surface [4,5,13,14]. One of the issues when conducting in vivo studies of this nature is the availability of suitable human teeth and other investigators have utilised an enamel substitute material (Macor® [3]) or an animal enamel model (Elephant tusk) [14]. For the present study, the enamel substitute material (Macor®) (Paolinelis et al. 2009) was used as the material to evaluate the effect of the selected bioactive glasses in air abrasion procedures on abrasivity. The rationale for using (Macor®) was that the material would act in a similar manner to that of enamel [3].

Prior to the present study there appeared to limited data on the effect of particle shape and size of Bioactive glasses on air abrasion procedures, a previous study by Mahmood et al. [15] showed the significance of particle size, grinding process and particle shape on abrasivity of bioactive glasses and indicated that increased particle size and angular particle shape were more abrasive to enamel. It should be noted however that this study was evaluated using a bioactive toothpaste on abrasivity of enamel. The results from the present study would suggest that particle size has a direct effect on both cut depth and abrasivity of the Bioactive glass samples in air abrasion using an enamel substitute material (Macor®) however, particle shape did not have any significant effect on air abrasion. It was evident that both angular and ball milled particles acted in a similar manner although slight differences were observed with the larger particle sizes where the angular particles tend to be more abrasive than the ball milled particles. These observations however contradicted previous results from Mahmood et al. [15] where there were significant differences in the abrasivity of the particle shape in tooth brushing the tooth surface. It can be postulated that the differences between this study and the present study may be due to 1) to the type of model/substrate used (human tooth compared to Macor) and 2) the material removal process being fundamentally different with air abrasion being dependant on the kinetic energy of particles striking the surface.

The results from the present study suggest that a BioMinF® glass powder was less abrasive than Sylec® of a similar particle size and as such may be a preferable material to use in air abrasion/air polishing procedures. An additional benefit of using a BioMinF® would be that the glass particles of the fluoro-calcium phospho-silicate glass can embed in the tooth surface giving a slow release of fluoride onto the tooth surface and forming a fluorapatite layer which is more acid resistant. The use of Macor® in this study was considered a poor substitute material for enamel, which was contrary to the study by Paolinelis et al. [3] and may have been due in part to the milder effect of using helium as a propellant as opposed to the system used in the present study.

Conclusion

The results from the present study would suggest that air abrasion/polishing with a BioMinF® glass powder would be a less abrasive alternative to a 45S5 glass powder (Sylec®) in polishing the tooth surface (enamel) with the additional advantage of localized fluoride release. However further *in vitro* studies are required using different substrates that more closely mimic human enamel when evaluating glass powders for air abrasion/polishing procedures.

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